Improved models for radiating edge-plasmas for ACT-1

1. Kinetic Monte Carlo neutrals for pumping
2. Multi-charge-state impurities for radiation

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Two issues addressed today

1. Previously, we have reported that the neutral pressure near the private-flux pumping region for both types of solutions is ~100 times that from ITER Organization's ITER simulations. Now using ITER parameters, we still find much large pressure. WHY?

2. Previous UEDGE ACT-1 simulations have used a basic coronal equilibrium impurity model with a specified impurity concentration. Our recent helium simulations with a more detailed multi-charge-state (MCS) model shows strong variations in concentration. WHAT EFFECT DOES MCS HAVE FOR NEON OR CARBON RADIATION?

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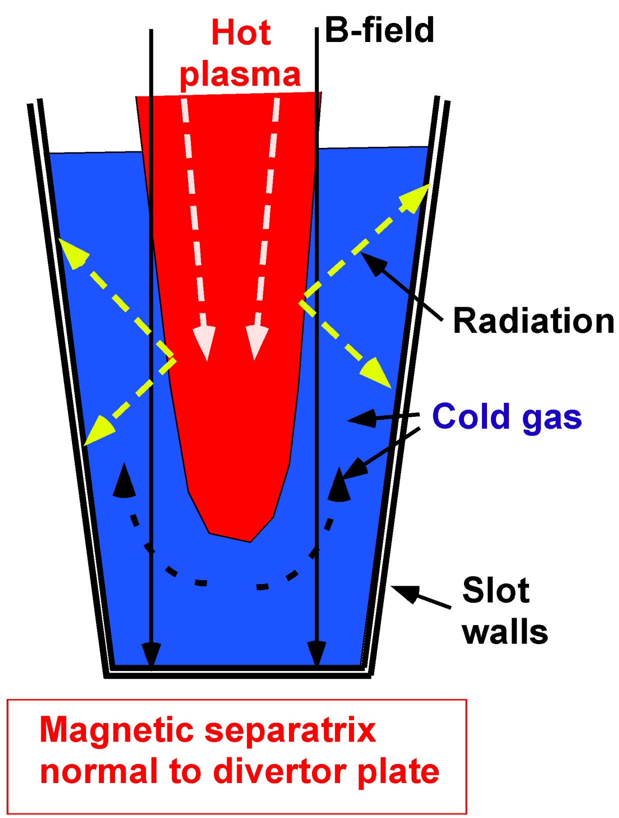
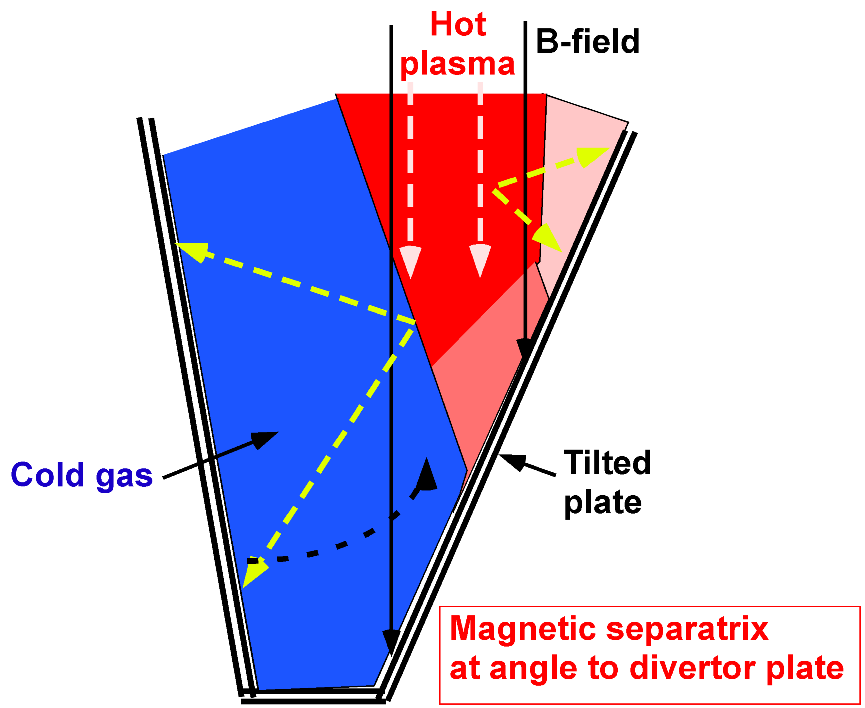
Reminder of two types of divertor configurations possible (hot plasma refers to plasma pressure)

<u>Fully-detached divertor plasma</u>



<u>Partially-detached divertor plasma</u>



Part 1: Neutral particle component of divertor plasma

1. **UEDGE models hydrogenic plasma, impurities and neutrals**

2. **Specify neutral pressure and particle throughput for pump design**

3. **Are ACT-1 results consistent with similar divertor in ITER design?**

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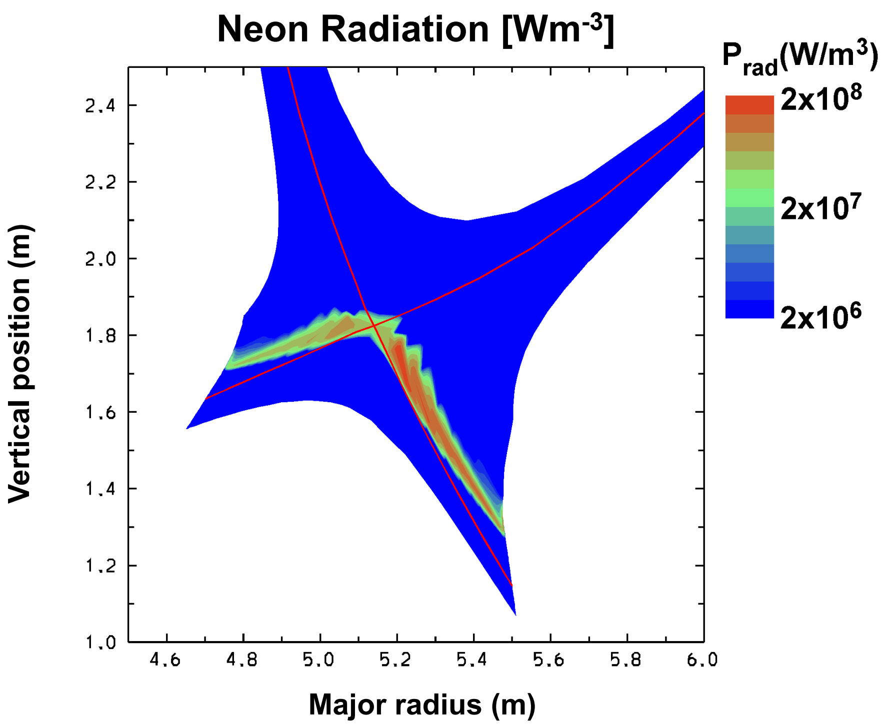
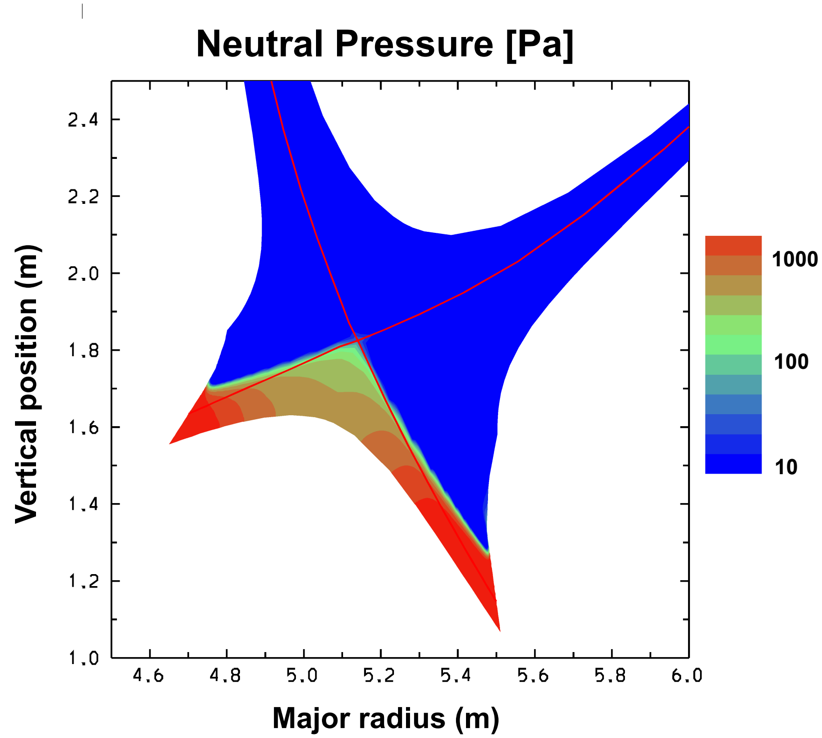
Partially detached plasma in ACT-1 exhibits unusually high neutral pressure in PF region





Average neutral pressure at inner leg on PF wall:

ACT-1	1240 Pa	from UEDGE simulation
ITER	480 Pa	from UEDGE simulation
ITER	~ 10 Pa	from ITER design team (Kukushkin - NF2005)

How does the UEDGE neutrals model differ from that used by the ITER design team?

Fluid neutrals	Kinetic neutrals
1. Neutral atom population is characterized locally by three parameters (n, v, T)	1. Neutral atom population is described locally by a velocity-space distribution f(v)
2. Molecules are not explicitly modeled	2. Neutral molecules are explicitly included as a separate species
3. Assume neutral atom temperature is same as background ions	3. Temperature of each neutral component is independently calculated

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Why don’t we use the more complete kinetic model in UEDGE?

1. Kinetic model run times are much longer than with fluid model:

   Self-consistent steady state requires ~ 3 hours CPU time for fluid model versus ~ 30 days CPU time for ITER kinetic model

   => impact on turn-around time for parameter exploration

2. Switching models in UEDGE might incur significant setup and verification costs

3. Fluid neutral model in UEDGE has been successfully benchmarked with kinetic models for strongly interacting plasma and neutrals (but may need kinetic model where neutrals dominate)

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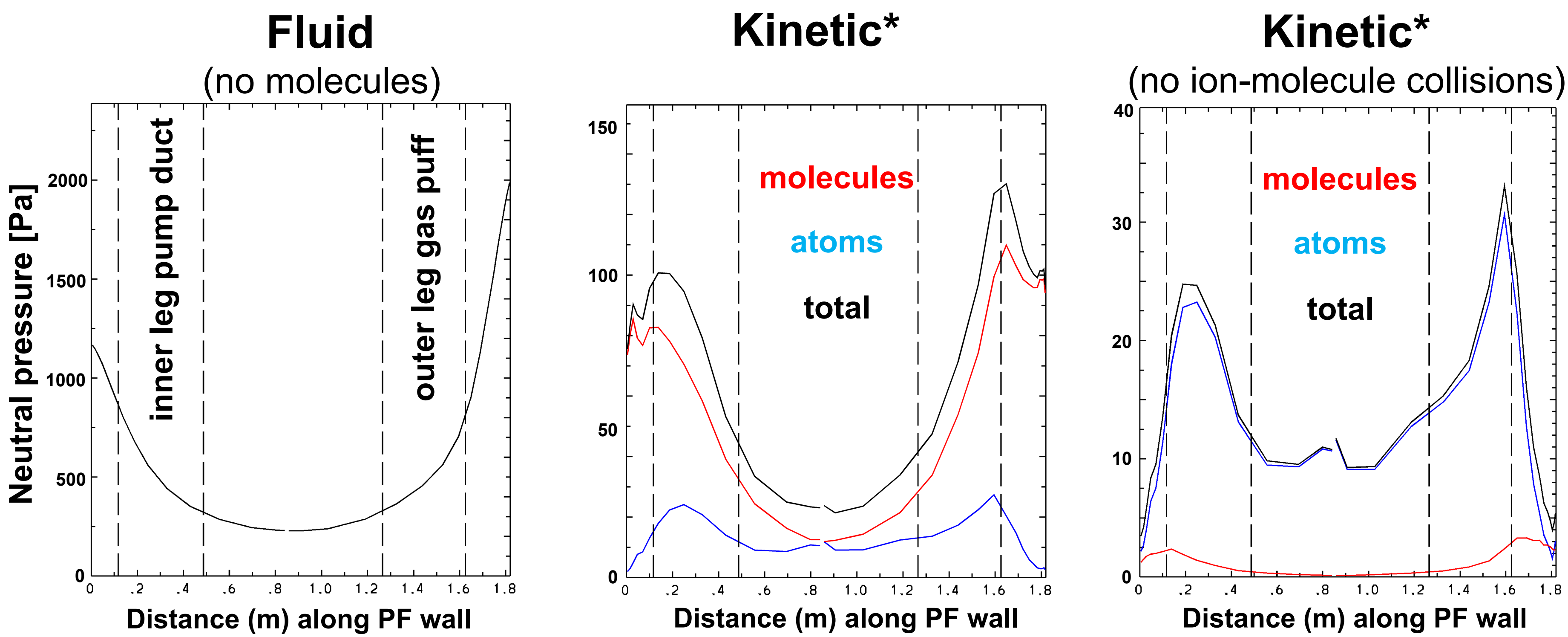
Neutral pressure profiles on the PF wall are sensitive to variations in the neutrals model

Simulate neutrals in a **fixed background plasma**
(partially-detached ITER divertor configuration)



$P_{n,inner}$ = 500 Pa

$P_{n,inner}$ = 80 Pa

$P_{n,inner}$ = 20 Pa

*DEGAS2 code (Stotler – JNM2001)

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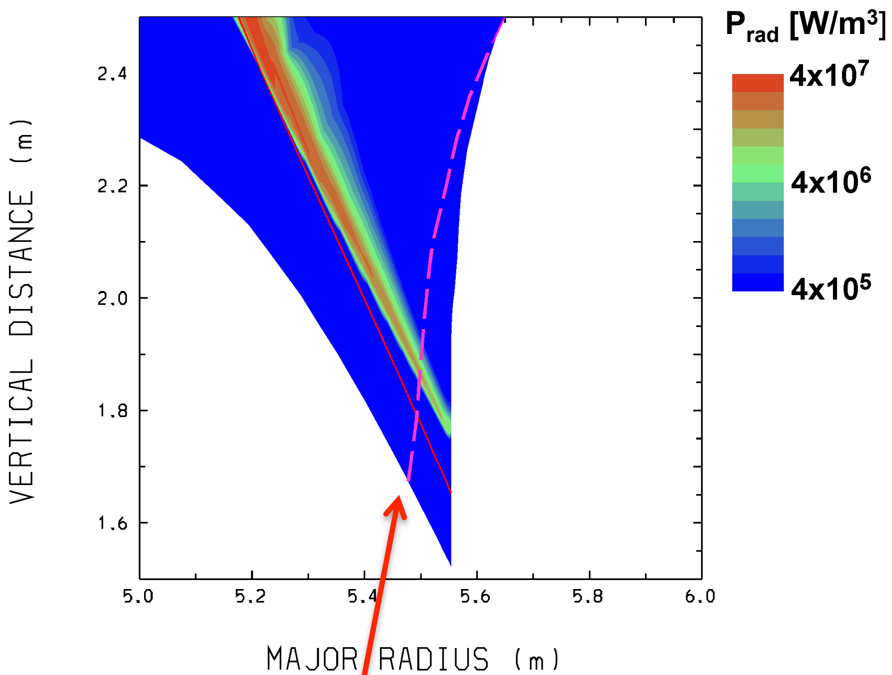
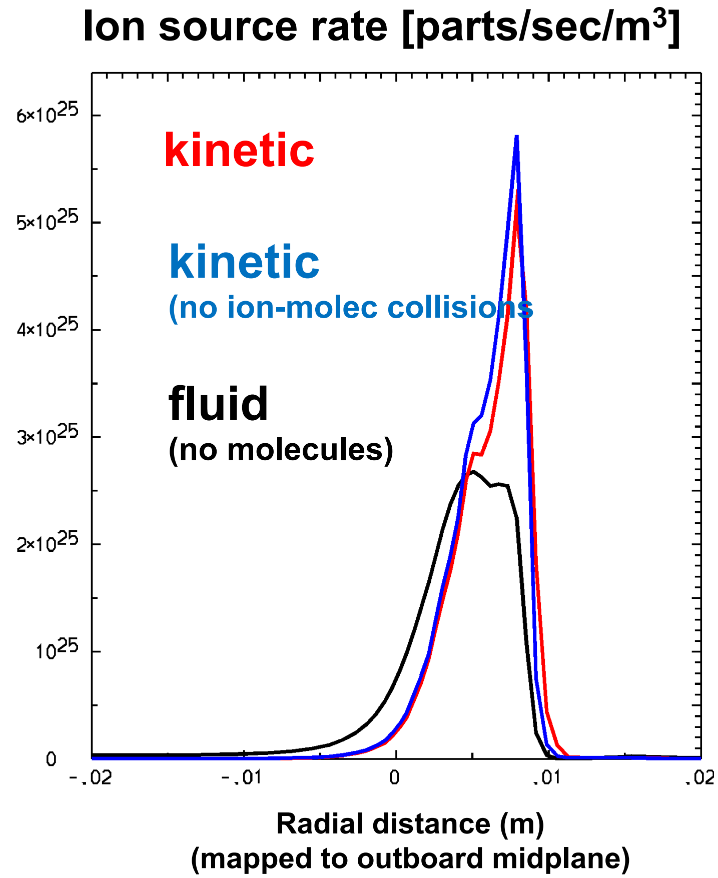
Location and strength of ionization source is not sensitive to variations in the neutrals model



Path for ionization profile shown in adjacent figure



These same model variations have a strong impact on the neutral pressure at the PF wall

Summary and Conclusion of Part 1 on Neutrals

1. Fluid neutrals model significantly over-estimates neutral pressure on PF wall

2. Fluid neutrals model is consistent with kinetic model in high heat flux, strongly radiating region of divertor

3. The PF region is effectively de-coupled from the strongly radiating region and can be modeled separately by a kinetic model

4. PF wall neutral pressure in ACT-1 is likely similar to ITER design, i.e., ~ 10 Pa at entrance to pump duct.

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Part 2: Comparing two impurity models – fixed-fraction versus multi-charge-state

- **Both models compute electron line-radiation loss term using**

  $d(3n_e T_e/2)/dt$ + transport terms = - $\mathcal{E}(T_e n_e) n_e n_{imp}$

  where $\mathcal{E}(T_e n_e)$ is the impurity emissivity.

- **SImple fixed fraction (FF) model specifies n_{imp}/n_e and takes $\mathcal{E}$ from a coronal equilibrium model (no impurity transport); it is fast**

- **The multi-charge-state (MCS) model follows individual charge states and computes n_{imp}/n_e locally. Here $\mathcal{E}$ includes transport effects. A key impurity equation added is parallel force balance:**

$$(u_{\|z} - u_{\|h}) m_h n_h \nu_{hz} = \left(-\frac{\partial P_z}{\partial s} + \alpha_z n_z \frac{\partial T_e}{\partial s} + \beta_z n_z \frac{\partial T_i}{\partial s} - \ Zen_z \frac{\partial \Phi}{\partial s} \right)$$

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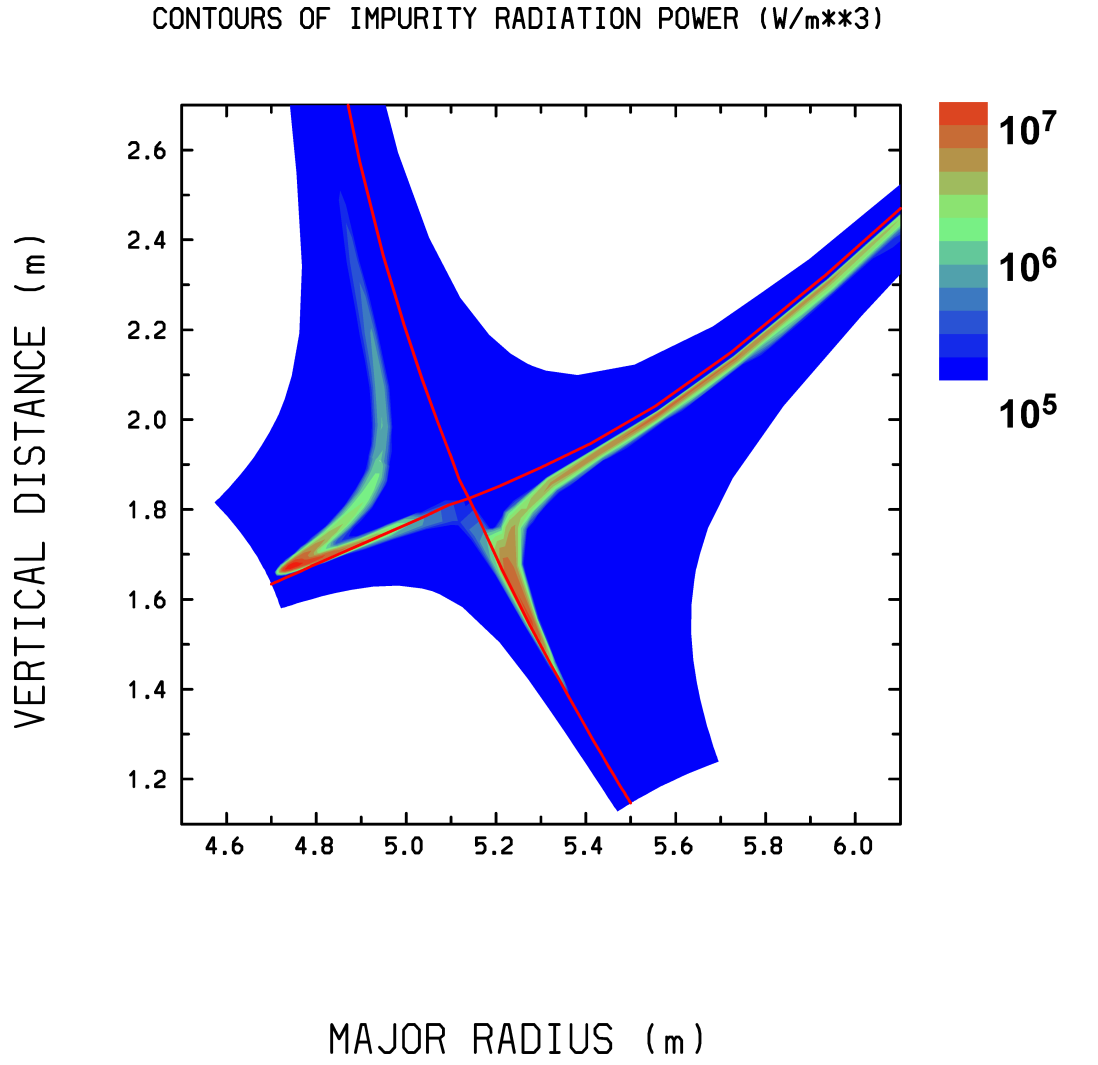
Consider a fully-detached, steady-state plasma ACT-1 solution with neon

Fixed-fraction model with n_{imp}/n_e = 0.004 (Z_{eff} = 1.4)



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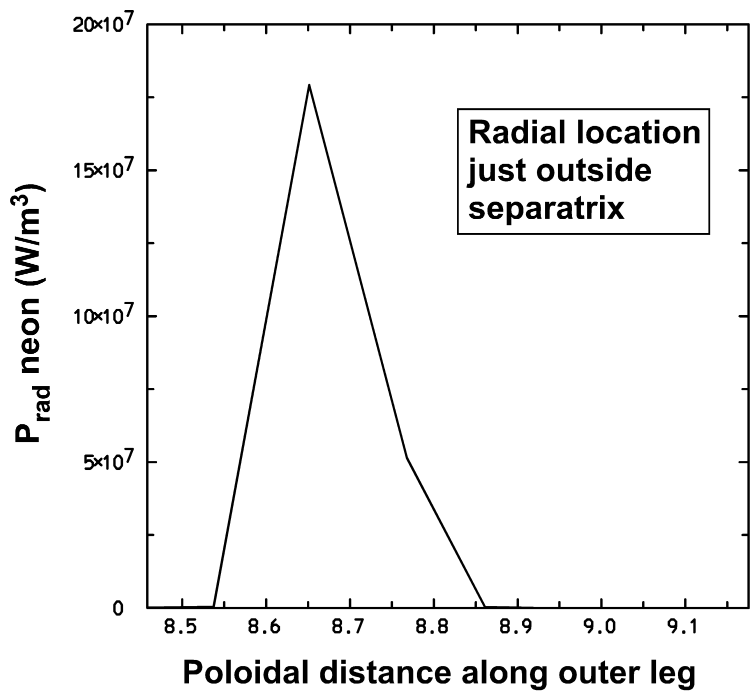
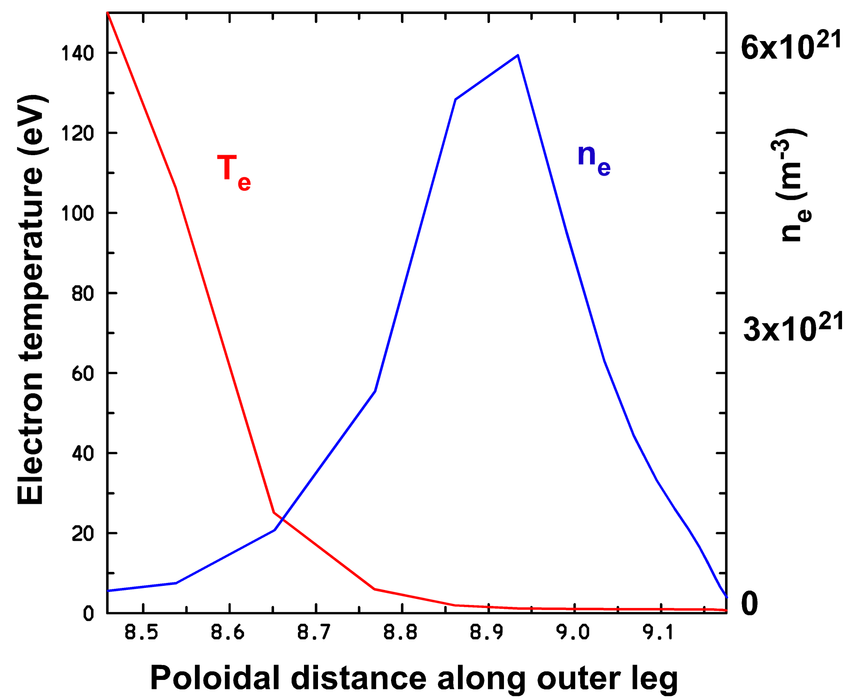
Poloidal profiles just outside separatrix show strong spatial variations





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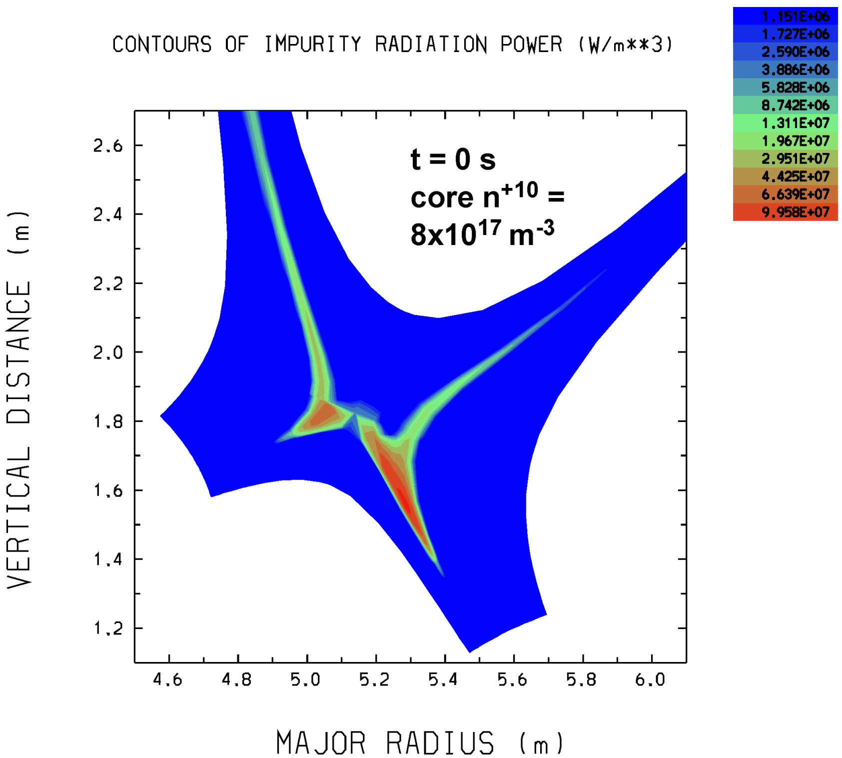
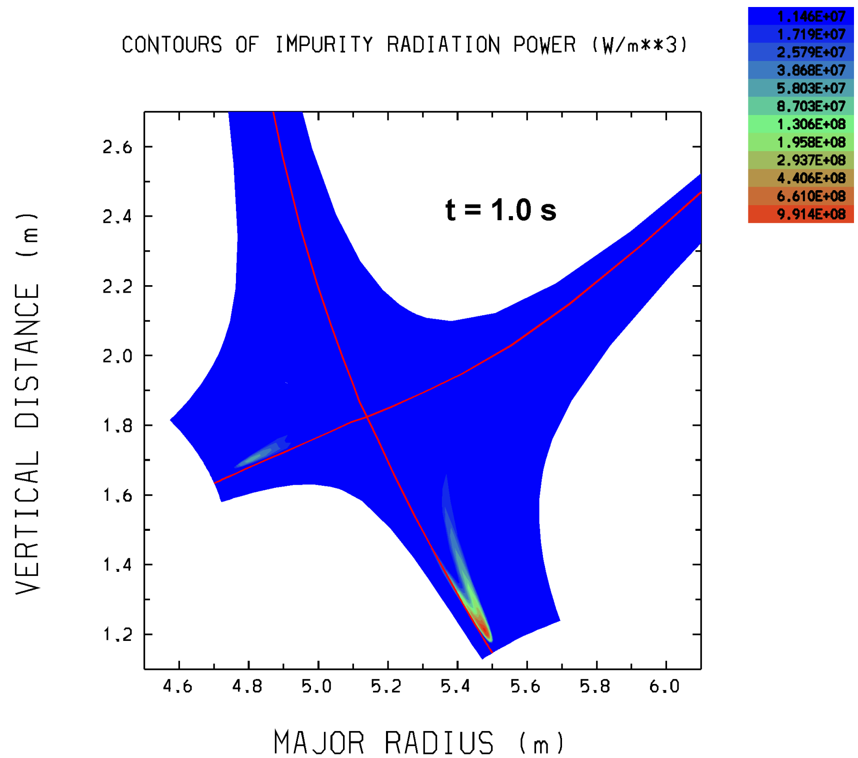
Switching to MCS impurity model shows a slowly evolving, fully-detached plasma

MCS model with n_{imp}/n_e = 0.008 on core boundary (Z_{eff} = 1.8)

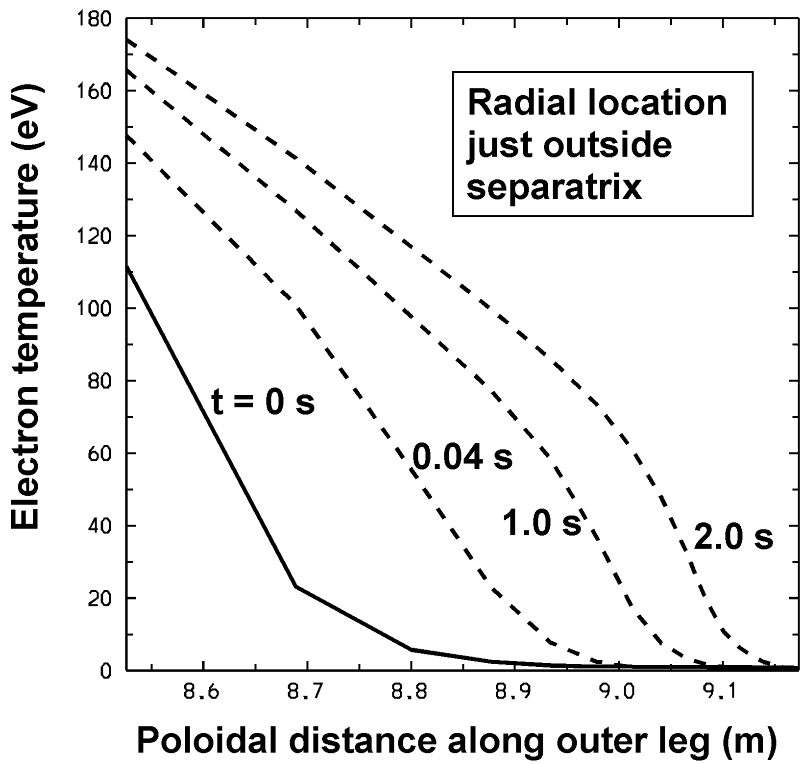




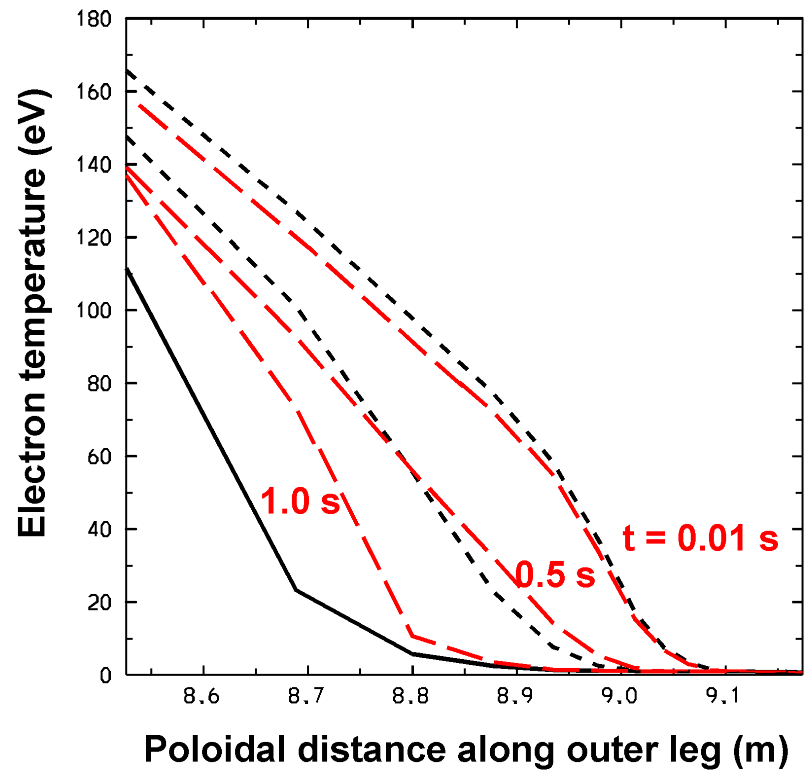
Slowly evolving, fully-detached plasma can be controlled by small adjustment to core bndy neon level

MCS model with n_{imp}/n_e = 0.008 on core boundary (Z_{eff} = 1.8)

Evolution of T_e profile for core n^{+10} = 8e17 1/m**3

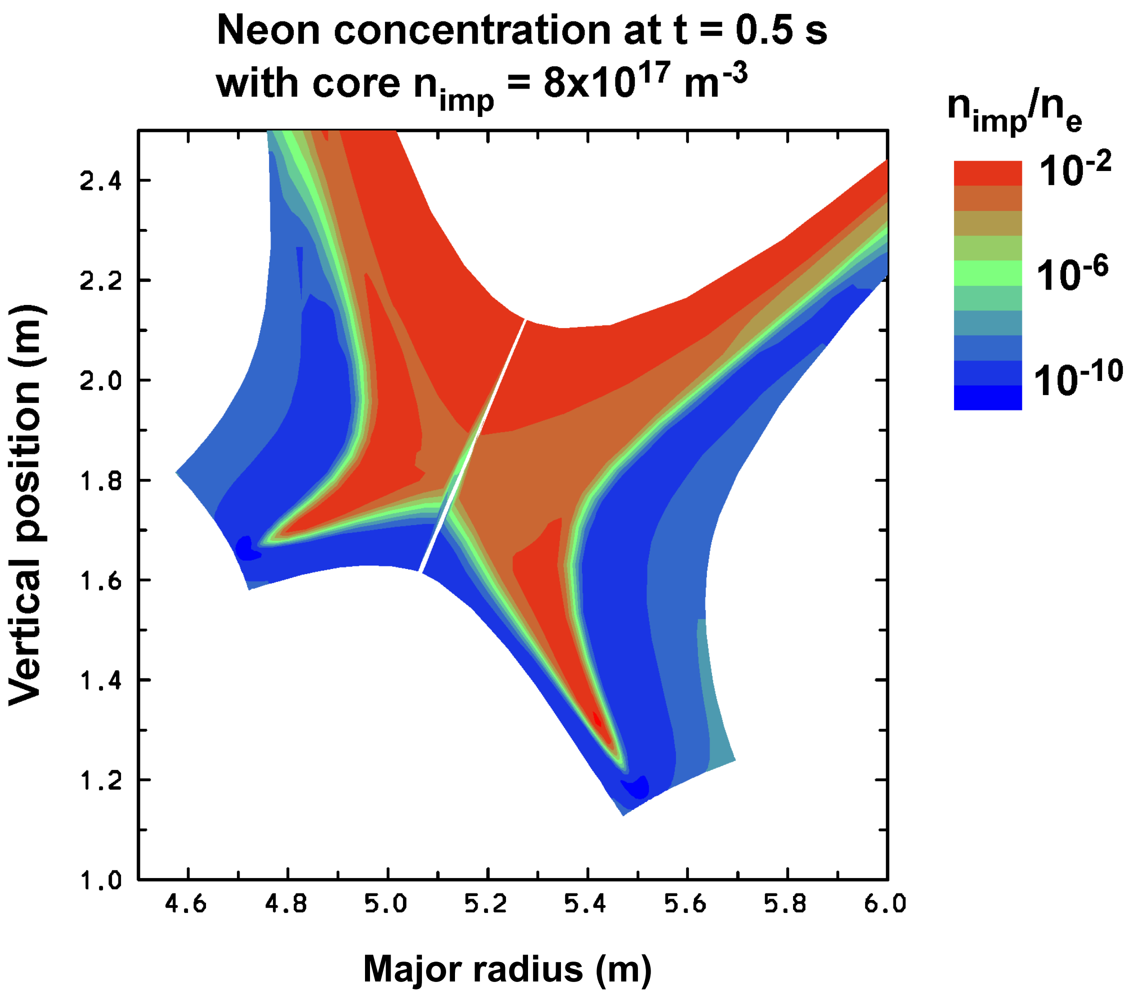


Return evolution when n^{+10} set to 10e17

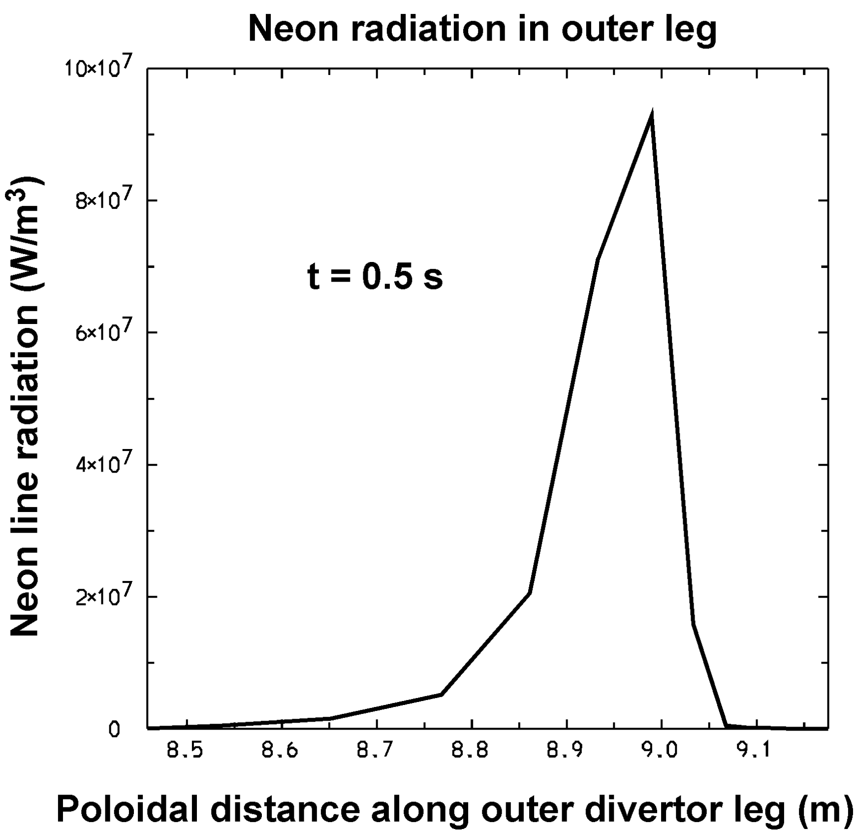


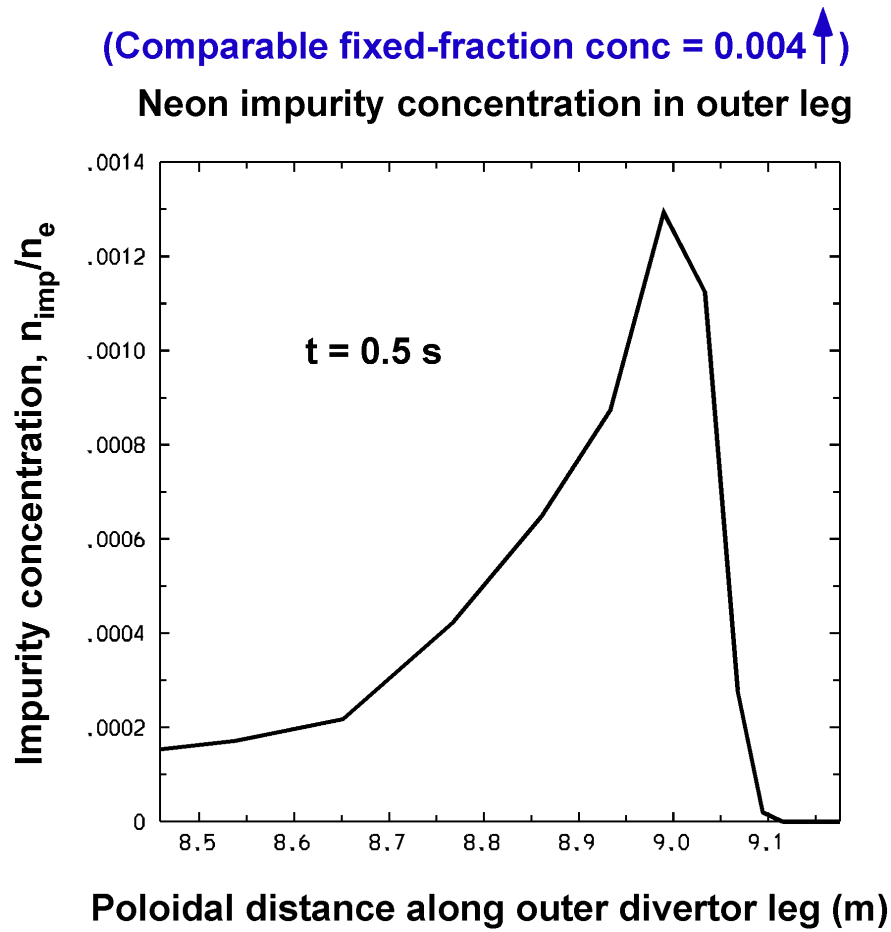
Neon concentration in scrap-off layer shows strong variations, yet is adequate for large radiative loss

MCS model with n_{imp}/n_e = 0.008 on core boundary (Z_{eff} = 1.8)



Poloidal profiles just outside separatrix fo MCS model also show strong spatial variations on concentration





Overall conclusions

- <u>For neutrals</u>
  – A (kinetic?) description is required with molecules and separate atomic/molecular energy equations to properly model the neutral-dominated pumping region, which should result in much lower neutral pressures; can we rationally scale from know ITER results?
  – Neutrals in the plasma-dominated region ($n_i > 0.1*n_g$) are reasonably described by the UEDGE fluid model
- <u>For impurities</u>
  – More detailed multi-charge-state model shows strong variations in concentration, but radiation levels are adequate for $Z_{eff} \sim 2$
  – Slowly evolving fully-detached plasma can be feedback stabilized